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DEVELOPMENT OF SUPERPLASTICIZED LIGHTWEIGHT HIGH-STRENGTH CONCRETE INCORPORATING STEEL FIBRES, SILICA FUME AND FLY ASH

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DEVELOPMENT OF SUPERPLASTICIZED LIGHTWEIGHT HIGH-STRENGTH CONCRETE INCORPORATING STEEL FIBRES, SILICA FUME AND FLY ASH

by

G.G. Carette*, H.S Wilson** and C.W. Tan***

ABSTRACT

This report presents the results of a study undertaken to develop superplasticized lightweight high-strength concrete containing steel fibres, silica fume and fly ash, with cement contents of 400, 500 and 600 kg/m^3. The mechanical properties of the concrete were determined from specimens prepared, cured and tested according to ASTM specifications. The fresh concrete properties studied were inverted slump-cone time, Vebe time, slump, unit weight and air content. The hardened concrete properties investigated were flexural strength, toughness-energy absorption, impact strength, compressive strength and splitting-tensile strength.

The density of the concrete was about 2000 kg/m^3. The compressive strength ranged from 40-65 MPa and the flexural strength ranged from 7 to 8.5 MPa at 28 days. Test data indicated a 20-fold increase in toughness over the mixture without fibres, as measured by the toughness index. Impact resistance also improved by 300 to 600%.

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MISE AU POINT D'UN BÉTON LÉGER SUPERPLASTIFIÉ À RÉSISTANCE ÉLEVÉE CONTENANT DES FIBRES D'ACIER, DE LA FUMÉE DE SILICE ET DES CENDRES VOLANTES

par

G.G. Carette*, H.S. Wilson** et C.W. Tan***

RÉSUMÉ

Le présent rapport comprend les résultats d'une étude faite en vue de mettre au point un béton léger, superplastifié et à résistance élevée contenant des fibres d'acier, de la fumée de silice et des cendres volantes et ayant des teneurs en ciment de 400, 500 et 600 kg/m^3. Les propriétés mécaniques du béton ont été déterminées à partir d'échantillons préparés, traités et soumis à des essais conformément aux spécifications de l'ASTM. Les propriétés du béton frais qui ont fait l'objet d'une étude étaient l'affaissement du cône en fonction du temps, le temps Vebe, l'affaissement, le poids par unité et le contenu en air. Les propriétés du béton durci qui ont été étudiées étaient la résistance à la flexion, l'absorption dureté-énergie, la résistance au choc et la résistance à la rupture et à la traction.

La densité du béton était d'environ 2000 kg/m^3. La résistance à la compression variait de 40-65 MPa et la résistance à la flexion variait de 7 à 8,5 MPa après 18 jours. Les données dérivées des essais ont démontré que la dureté de ce mélange était 20 fois plus considérable que celle du mélange sans fibres, comme l'indiquait l'indice de dureté. La résistance au choc a également subi une amélioration de 300 à 600 % .

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INTRODUCTION

One major drawback of high-strength concrete is its brittleness, resulting in failure which can be sudden and catastrophic. Steel fibre-reinforced concrete has been shown to overcome this disadvantage as steel fibres improve ductility, flexural strength, impact strength and failure toughness. To reduce balling in mixing, steel fibres with deformed ends, glued together in bundles with water-soluble adhesive, are used.

The possible applications of a superplasticized lightweight concrete with high compressive- and flexural strengths, low permeability and good toughness-energy absorption, are in offshore structures and high-rise construction. However, the proportioning of such a concrete should be carefully made and concrete tested before any field application be considered.

SCOPE OF INVESTIGATION

The major objectives of this investigation are:

1. To compare the mechanical properties of superplasticized lightweight concrete, with and without steel fibres, with all concrete containing 10% fly ash and 5% silica fume of the cement as additions.

2. To determine the influence of cement content on the properties of fresh and hardened steel fibre-reinforced concrete for a constant percentage of silica fume and fly ash.

The test program consisted of an evaluation of non-air-entrained concrete containing Type 1 Portland cement, fly ash, silica fume, lightweight coarse aggregate, natural sand fine aggregate, and steel fibres with a superplasticizer for improvement in workability. The fresh concrete properties examined were slump, Vebe time, inverted slump-cone time, unit weight and air content. The mechanical properties studied included the compressive strength, splitting-tensile strength, flexural strength, toughness-energy absorption and impact resistance.

A total of six 0.07 m^3 mixtures were made, each consisting of two batches, as follows:

(1) Series A: Reference mixtures consisted of lightweight concretes with three different cement contents at constant additions of 10% fly ash and 5% silica fume.

(2) Series B: Steel fibre-refinforced concrete mixtures consisted of the reference mixes with the addition of steel fibres.

MATERIALS

Cement:
Type 1 Portland cement satisfying ASTM was used. Its physical and chemical properties are shown in Table 1.

Fly ash:
Class F fly ash from Sundance, Canada, meeting the requirement of ASTM C618 was used. The particles are typically spherical with diameters ranging from 1 to 150 μm. Table 1 gives the physical and chemical properties of the fly ash. Fly ash contributes improvement in strength at later ages (1).

Silica fume:
Condensed silia fume from a silicon alloy plant in Quebec, Canada was used. The fume consists of very fine spherical particles with specific surface area of 20,000 m^2/kg and an average diameter of 0.1 μm. Silica fume, by virtue of its fineness and active pozzolanic properties, increases strength and impermeability of concrete considerably (2). With the use of silica fume in concretes of low water-cement ratio, superplasticizers are needed to maintain workability.

Aggregates:
The lightweight aggregate was from New Brunswick. It was a shale expanded by the rotary-kiln method (3). It came in 2 lots; the odd-numbered batches were made with lot 1 aggregate and even-numbered batches were made with lot

2 aggregate. The fine aggregate was natural sand from Ottawa. The relative densities (SSD), absorption (ASTM C127 and C128), unit weight and gradings of the coarse and fine aggregates are given in Table 2.

Steel fibres:

The steel fibres used had hooked ends and were glued together side by side into bundles with a water-soluble adhesive. They were Dramix ZP 30/0.5 and were made from low carbon steel wires with a normal length of 30 mm. When the glue is dissolved by water in the mix, the fibres separate out as individual fibre with an aspect ratio of 60. Figure 1 shows a sample of the steel fibres used.

Superplasticizer:

A sulphonated naphthalene formaldehyde condensate was used. This dark brown 42% solids aqueous solution had a density of 1200 kg/m^3 and a negligible chloride content.

CONCRETE MIXES

Mix proportions are summarized in Table 3. For each series (A and B), the cement contents were approximately 400, 500 and 600 kg/m^3. Also, 5% silica fume and 10% fly ash by weight of the cement were added. The superplasticizer was added to achieve the desired workability.

The room dry coarse and fine aggregates were soaked for 24 hours before mixing and the amount of mixing water was subsequently adjusted according to the water absorbed by the aggregates. The mixing procedure for series B was as follows:

The coarse aggregate was placed together with the steel fibres in the pan mixer and the cementitious materials (cement, fly ash and silica fume) and mixing water were added simultaneously. The mixing time was about 3 minutes. Following this, the fine aggregate was added and mixing continued for another 3 minutes. The workability was then adjusted by the addition of superplasticizer and mixing was resumed for 2 minutes. The mixing procedure for series A was similar to that of B except there were no fibres in the mixture.

The properties of the fresh concrete i.e. slump, inverted slump-cone time, unit weight and air content were determined immediately after the final mixing. Table 4 summarizes the properties of the fresh concrete. The table does not include the Vebe time since the test was discontinued after two batches. The detailed description for inverted slump-cone test is found in the Appendix (proposed ASTM C995-83).

PREPARATION AND CASTING OF SPECIMENS

Test cylinders (102 x 203 mm, 152 x 305 mm and 152 x 64 mm) and prisms (76 x 102 x 406 mm) were cast according to the schedule in Table 5. The cylinders were cast in plastic moulds, with the exception of 2 cylinders for 7-day splitting tensile strength test and 2 cylinders for 91-day compressive strength test. Those cylinders and the prisms were cast in steel moulds. They were all cast and compacted in 2 layers using a vibrating table except for the 152 x 305 mm cylinders which were compacted by an internal vibrator.

After moulding, all the specimens were covered with wet burlap and left in the mixing room for 24 hours at 23°C, after which they were demoulded and transferred to a standard moist-curing room until required for testing.

TESTING OF SPECIMENS

The prisms were tested at 7, 14, and 28 days for flexural strength and toughness, using third point loading according to ASTM C78. A dial gauge was placed below the midspan of the prism to measure deflection as load increased. Load levels at first crack (the point at which the load-deflection curve deviates from linearity), at maximum load and at centre deflection of 1.905 mm, were noted. Figure 2 shows the typical load-deflection curve of fibre-reinforced concrete. The toughness index was calculated as the area under the load-deflection curve to a deflection of 1.905 mm divided by the area under the load-deflection curve of prisms containing fibres up to the first crack strength.

The 102 x 203 mm cylinders were tested for compressive strength and splitting-tensile strength. The compressive strength test was done at 7, 28 and 91 days according to ASTM C39. The splitting-tensile test was done at 7 and 28 days according to ASTM C496.

The 152 x 305 mm cylinder was cut to a thickness of 64 mm, lapped at the moulded end to ensure a flat surface and then tested for impact strength. The equipment for this test is shown in Figure 3 (Ref. 5). The 4.5 kg (10 lb) drop hammer (ASTM D1557) was placed with its base on the steel ball and it was dropped repeatedly 457 mm onto the steel ball. The number of blows required to cause the first visible crack and ultimate failure was recorded. The ultimate failure is the point when the cracks are opened sufficiently so that the pieces of concrete are touching 3 of the 4 positioning lugs on the baseplate.

TEST RESULTS

A total of 156 cylinders, 102 x 203 mm in size, 6 cylinders, 152 x 305 mm in size, 6 cylinders, 152 x 65 mm in size and 108 prisms, 76 x 102 x 406 mm in size were tested in this investigation. Their densities at various ages are recorded in Table 6. A summary of the test results for mix series A and B are shown in Table 7. Figures 4 and 5 compare the compressive and flexural strength performance of the steel fibre reinforced concrete with that of concrete without fibres. The toughness and impact resistance characteristics are illustrated in Figure 5 and 6 respectively.

DISCUSSION OF TEST RESULTS

Properties of Fresh Concrete

A number of papers have been published on the subject of steel fibre-reinforced concrete using steel fibres with deformed ends (4,5,6). No problem of balling with the steel fibres used in this study was encountered. Ramakrishnan et al (6) have reported the use of the inverted slump-cone time and Vebe time as tests for workability of steel fibre-reinforced concrete. However, the Vebe test (BS 1881) which was recommended for concrete with low workability was found to be unsuitable in

this study as the Vebe time was in the order of 2 to 3 seconds. On the other hand, the inverted slump-cone time, in the order of 10 to 20 seconds, gave an indication of workability. The time generally decreases with the increase in slump and hence increase in workability. With more data, a correlation between slump and inverted cone time may be found. With the same amount of superplasticizer added, the slumps of mixes containing fibres were about 50% of those of the mixes containing no fibres. However, the result was still a good workable mix. With the increasing use of superplasticizer, the slump test may still be the most preferred test for workability of steel fibre-reinforced concrete.

Properties of Hardened Concrete

Compressive Strength

Figure 4 gives the compressive strength versus age relationship for the various cement contents. The compressive strength increased proportionally for each 100 kg/m^3 increase in cement content, attaining 68 MPa at 91 days. The mixes with and without steel fibre are comparable in their compressive strengths.

Splitting-Tensile Strength

It was observed that the splitting-tensile test was not an appropriate test for these steel fibre-reinforced concrete. Unlike the reference series A, the steel fibre-reinforced concrete specimens were deeply compressed and deformed at the 2 lines of contact with the platens of the testing machine and did not break sharply into halves. The results in Table 7 shows a two-fold increase in splitting-tensile strength for specimens of series B over those of A. Like the compressive strength, the splitting-tensile strength increases with increase in cement content.

Flexural Strength

Figure 5 illustrates the strength gain in flexure with increasing cement content and age. However, there seems to be no significant difference in flexural strength between the concrete with and without fibres, except for mixes A6 and B6 where there was a 13% decrease for the steel fibre-reinforced concrete.

Toughness-energy Absorption

The toughness indices of steel fibre-reinforced concrete are in the order of 15 to 22. The results shown in Table 7 and Figure 6 generally indicate a slight reduction in toughness index with increase in cement content.

Impact Strength

The impact strength of the steel fibre-reinforced concrete is about 3 to 6 times higher than that without fibres as seen from Table 7 and Figure 7. It is noted that the number of blows from the first crack to ultimate failure is increased significantly in the steel fibre-reinforced concrete while the concrete without steel fibres resulted in ultimate failure soon after the first crack.

CONCLUDING REMARKS

Satisfactory lightweight high strength of the order of 50 to 60 MPa can be achieved with lightweight aggregate concrete incorporating silica fume and fly ash. With the proper mix proportioning, a good workable mix can be obtained with steel fibres. Due to the wider use of super-plasticizer, the Vebe time test has become unsuitable and the inverted slump-cone test unnecessary. The compressive- and flexural strength of steel fibre-reinforced concrete are comparable to those without fibres. However, the toughness and impact resistance are greatly improved in concrete with steel fibres. Subjecting the steel fibre-reinforced concrete to the splitting-tensile strength test is not recommended. This study has been a preliminary one, and hence further investigation would be required to determine the behaviour of high-strength concrete using different lengths and quantity of fibres, in the area of shrinkage, freezing and thawing, corrosion, creep and elastic modulus.

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Table 1. Physical properties and chemical analysis of cement and fly ash

Description of Test	Portland Cement (ASTM type 1)	Fly Ash
Physical Tests - General		
Fineness		
75 μm (passing)	94.5%	-
45 μm (passing)	81.2%	81.0%
Surface Area, Blaine	352 m^2/kg	360 m^3/kg
Specific Gravity	-	2.14 g/cc
Physical Tests - Mortar Strength		
Compressive Strength of 50 mm cubes at		
3 days	17.6 MPa	-
7 days	23.4 MPa	-
28 days	30.6 MPa	-
Pozzolanic Activity Index		
with lime	-	6.9 MPa
with portland cement	-	88.6%
Chemical Analysis		
Insoluble residue	0.08%	-
Silicon dioxide, (SiO_2)	21.50%	54.69%
Aluminium oxide, (Al_2O_3)	4.06%	25.02%
Ferric oxide, (Fe_2O_3)	2.58%	4.13%
Calcium oxide, (CaO), total	63.81%	
Magnesium oxide, (MgO)	3.07%	12.49%
Sulphur trioxide (SO_3)	2.88%	1.25%
Loss on ignition	1.35%	0.30%
		0.29%
Compound Composition		
Tricalcium silicate, (C_3S)	53.30%	-
Dicalcium silicate, (C_2S)	21.21%	-
Tricalcium aluminate, (C_3A)	7.03%	-
Tetracalcium aluminoferrite (C_4AF)	7.85%	-

Table 2. Grading, specific gravity absorption, and unit weight for coarse and fine aggregates

Grading Size, Percentage Passing (by weight)	Lightweight Aggregate, Lot 1	Lightweight Aggregate, Lot 2	Fine Aggregate	ASTM C330 Specification	ASTM C33 Specification
19.0 mm	100	100	-	90-100	-
12.5 mm	76.1	73	-	-	-
9.5 mm	48.3	45.5	-	10-50	100
4.75 mm	0	0	100	0-15	95-100
2.36 mm	-	-	90	-	80-100
1.18 mm	-	-	67.5	-	50-85
600 µm	-	-	42.5	-	25-60
300 µm	-	-	20	-	10-30
150 µm	-	-	6	-	2-10
Bulk Specific Gravity (SSD)	1.65	1.68	2.68	-	-
Absorption, %	4.60	4.65	1.10	-	-
Unit weight, kg/m^3	852	868	-	880 (max)	-

Table 3. Mixture proportions

Mix Series	Batch Number	Batch Quantities, kg/m³							Superplasticizer, % by weight of cementitious material
		Cement	Fly ash	Silica fume	Fine Aggregate	Coarse Aggregate	Water	Fibres	
A	1	409	41	20	675	677	171	-	0.65
	2	404	40	21	688	687	171	-	0.70
	3	510	51	26	568	677	178	-	0.86
	4	499	50	25	563	684	178	-	0.82
	5	602	60	30	462	661	183	-	1.07
	6	597	60	30	461	675	181	-	0.98
B	1	404	40	20	661	662	169	60	0.80
	2	403	40	20	678	677	170	60	0.88
	3	505	50	25	556	662	177	60	0.86
	4	497	50	25	554	672	178	60	0.82
	5	597	59	30	451	647	180	59	1.07
	6	586	59	29	448	653	177	59	1.08

Table 4. Properties of fresh concrete

Mix Series	Batch Number	Initial Slump, mm	Slump after addition of superplasticizer, mm	Inverted slump-cone time, s	Density, kg/m³	Entrapped Air, %
A	1	30	120	-	1992	2.1
	2	25	100	-	2011	2.2
	3	10	210	-	2011	1.6
	4	5	165	-	1998	1.8
	5	5	190	-	1998	1.4
	6	0	215	-	2004	2.4
B	1	5	85	19.0	2017	1.8
	2	5	70	22.0	2049	2.4
	3	0	90	12.0	2036	2.5
	4	0	85	18.0	2036	3.0
	5	0	150	11.5	2024	2.2
	6	0	165	14.0	2011	2.8

Table 5. Number of test specimens cast for each batch

Tests \ Batch Number	Series A						Series B					
	1	2	3	4	5	6	1	2	3	4	5	6
No. of cylinders (102 x 203) for compression test at: 7 days	3	3	3	3	3	3	3	3	3	3	3	3
28 days	3	3	3	3	3	3	3	3	3	3	3	3
91 days	-	2	-	2	-	2	-	2	-	2	-	2
No. of cylinders (102 x 203) for splitting-tensile test at: 7 days	3	3	3	3	3	3	3	3	3	3	3	3
28 days	3	3	3	3	3	3	3	3	3	3	3	3
No. of prisms (76 x 102 x 406) for flexural strength test at: 7 days	3	3	3	3	3	3	3	3	3	3	3	3
14 days	3	3	3	3	3	3	3	3	3	3	3	3
28 days	3	3	3	3	3	3	3	3	3	3	3	3
No. of cylinders (152 x 305) for impact strength at 28 days	-	1	-	1	-	1	-	1	-	1	-	1
No. of cylinders (152 x 64) for impact strength at 28 days	-	1	-	1	-	1	-	1	-	1	-	1

Table 6. Densities of cylinders and prisms at various ages

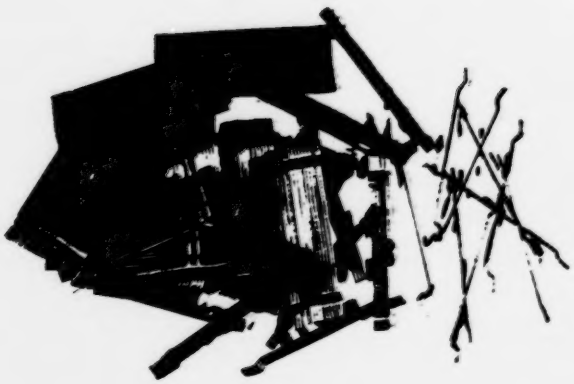
Mix Series	Batch Number	102 x 203 mm Cylinders, kg/m³				76 x 102 x 406 mm Prisms, kg/m³			
		1 day[1]	7 days[2]	28 days[2]	91 days[3]	1 day[4]	7 days[5]	14 days[5]	28 days[5]
A	1	1980	1956	1948	-	1977	2019	2039	2012
	2	1990	1979	1974	1988	1986	2066	2058	2025
	3	1990	1961	2000	-	1969	2013	2038	2037
	4	1980	1954	1965	1995	1969	2050	2040	2051
	5	2020	2001	1980	-	1998	2045	-	2056
	6	2000	1982	1985	2005	1983	2066	2057	2049
B	1	2020	2001	2003	-	2033	2095	2085	2094
	2	2030	2019	2016	2051	2026	2122	2130	2113
	3	2040	2023	2026	-	2033	2140	2093	2107
	4	2030	2006	2007	2033	2031	2115	2106	2107
	5	2040	2026	2005	-	2022	2085	-	2082
	6	2010	2002	2005	2015	1999	2077	2079	2039

Note 1: The density is an average of 12 results
2: The density is an average of 6 results
3: The density is an average of 2 results
4: The density is an average of 9 results
5: The density is an average of 3 results

Table 7. Properties of hardened concrete

Mix Series	Batch Number	Compressive Strength, MPa			Splitting tension, MPa		Flexural Strength, MPa			Toughness Index			Impact Strength* Number of blows	
		7 days	28 days	91 days	7 days	28 days	7 days	14 days	28 days	7 days	14 days	28 days	Sawn	Cast
A	1	41.8	52.0	-	2.8	4.4	5.3	6.6	6.6	-	-	-	-	-
	2	40.0	55.2	61.5	3.7	4.7	6.2	6.3	6.9	-	-	-	90/98	85/97
	3	49.8	60.1	-	3.9	5.3	6.0	7.4	7.8	-	-	-	-	-
	4	51.7	61.8	64.5	4.2	5.4	6.4	7.8	7.8	-	-	-	145/150	80/85
	5	55.2	66.6	-	5.4	5.4	7.6	8.0	8.4	-	-	-	-	-
	6	56.0	64.9	68.7	4.7	5.6	7.2	6.9	9.0	-	-	-	25/51	58/84
B	1	43.4	56.6	-	6.1	7.4	5.9	6.3	7.1	22.8	21.8	21.8	-	-
	2	41.3	55.5	61.3	6.1	7.3	6.4	6.5	6.6	21.8	19.9	21.2	363/519	300/900
	3	49.5	61.4	-	6.8	7.6	6.9	8.0	7.6	19.9	17.1	18.8	-	-
	4	52.3	62.6	65.2	7.0	7.7	7.1	7.4	7.6	15.7	20.1	18.9	325/550	350/425
	5	55.2	65.1	-	7.4	8.5	6.9	8.0	7.9	18.6	15.3	21.9	-	-
	6	56.2	61.7	66.1	7.5	7.6	8.0	7.7	7.8	18.1	15.0	15.3	155/333	350/575

*The first number the number of blows required to cause first crack and the second number is the number of blows required for ultimate failure



30 mm Fibres

Fig. 1. Steel fibres

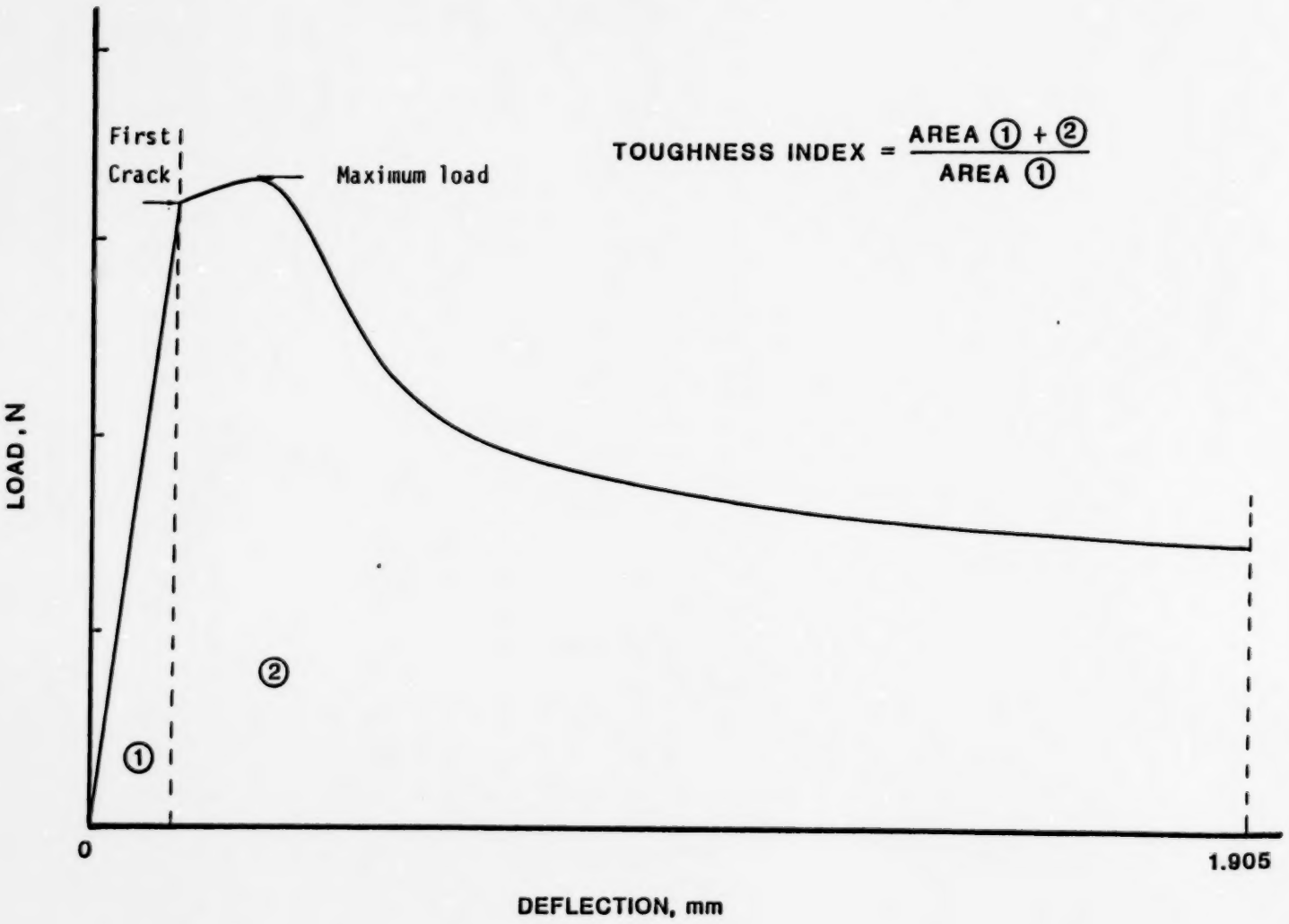


Fig 2. Load-Deflection curve for a typical steel fiber-reinforced prism

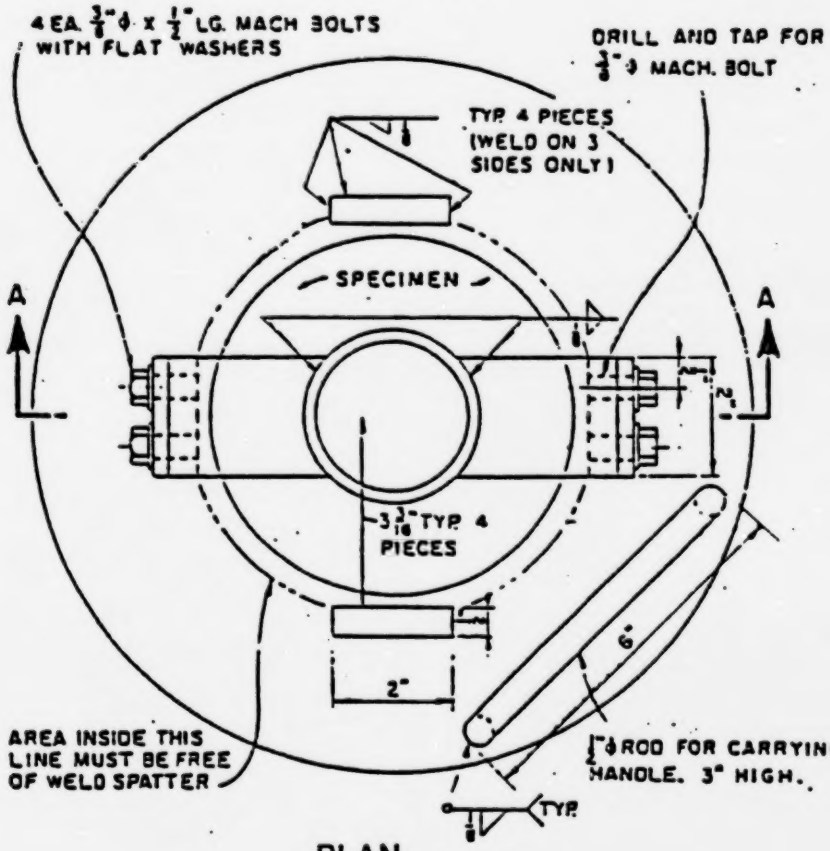
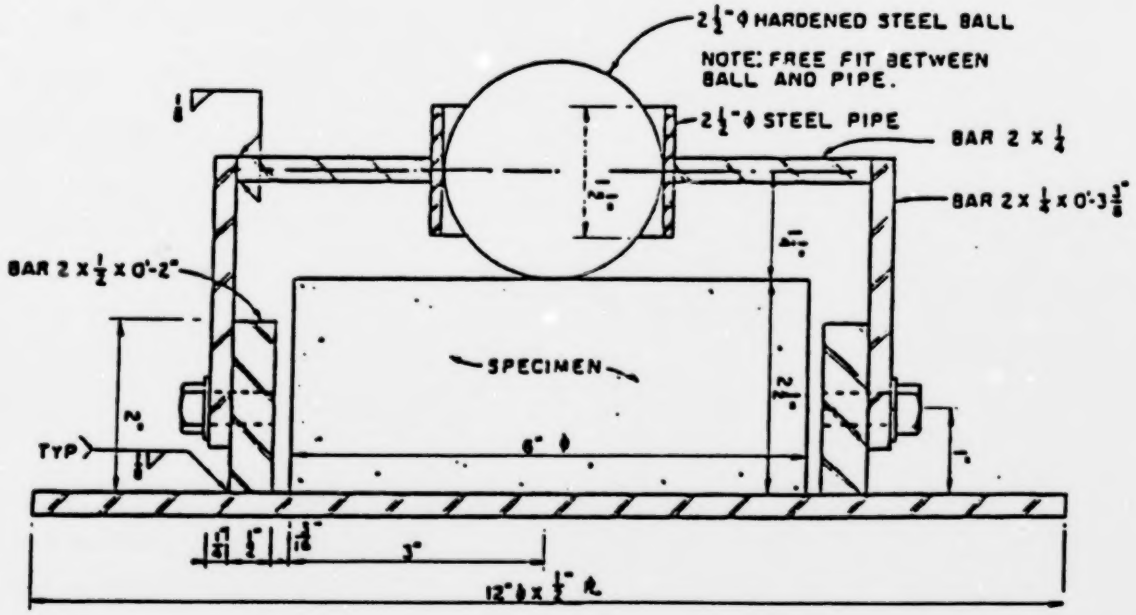

4 EA. 3/8" ϕ x 1/2" LG. MACH BOLTS WITH FLAT WASHERS
DRILL AND TAP FOR 3/8" ϕ MACH. BOLT
TYP 4 PIECES (WELD ON 3 SIDES ONLY)
SPECIMEN
A
A
3 3/16" TYP 4 PIECES
2"
6"
AREA INSIDE THIS LINE MUST BE FREE OF WELD SPATTER
1/2" ϕ ROD FOR CARRYING HANDLE. 3" HIGH.
TYP
PLAN

Fig.3 Test equipment for impact strength


2 1/2" ϕ HARDENED STEEL BALL
NOTE: FREE FIT BETWEEN BALL AND PIPE.
2 1/2" ϕ STEEL PIPE
BAR 2 x 1/4
BAR 2 x 1/4 x 0'-3 3/8"
BAR 2 x 1/2 x 0'-2"
SPECIMEN
TYP
6" ϕ
3"
12" ϕ x 1/2" R.
SECTION - A

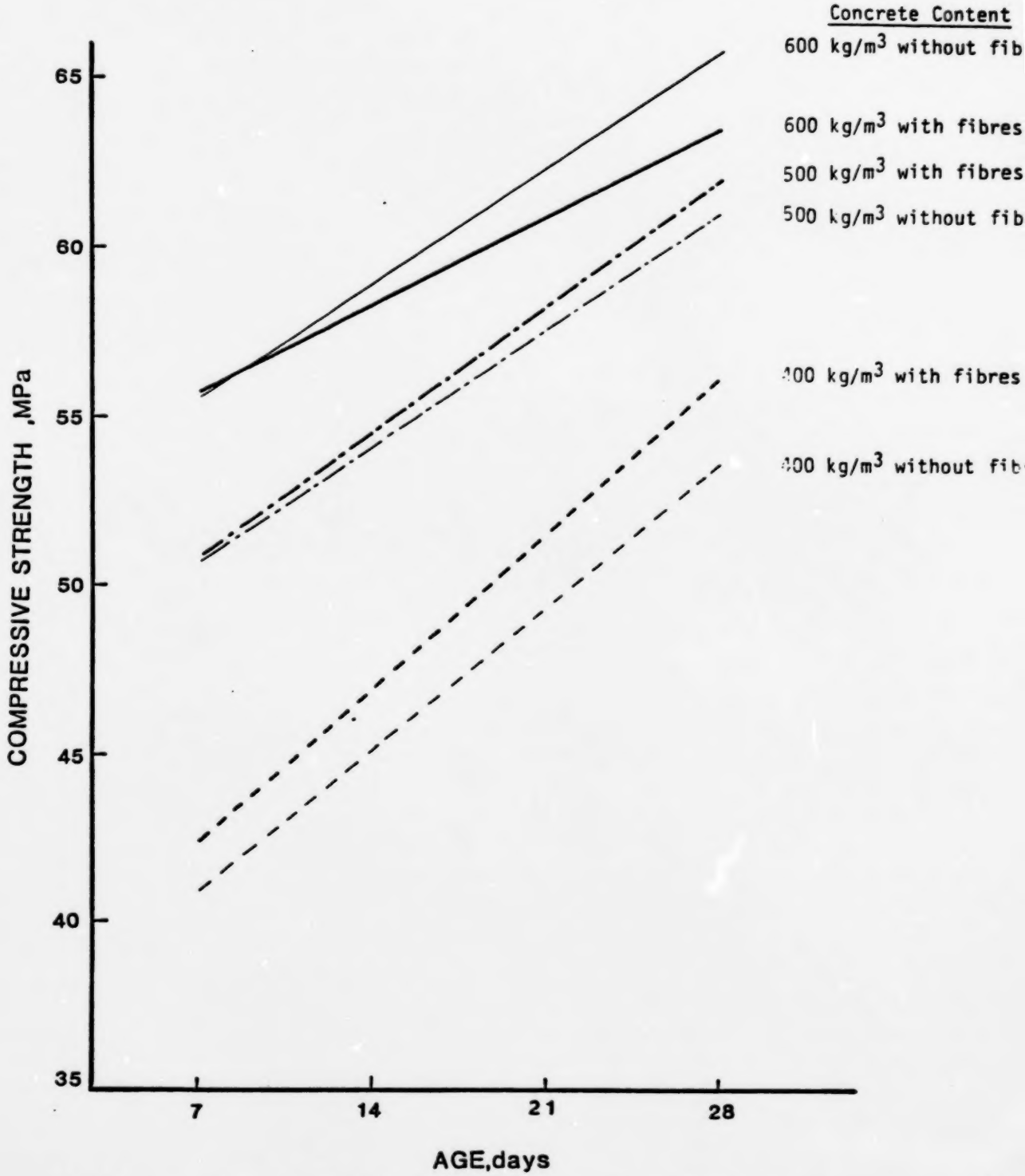


Fig. 4 Graph of compressive strength of concrete with and without steel fibres at different cement contents.

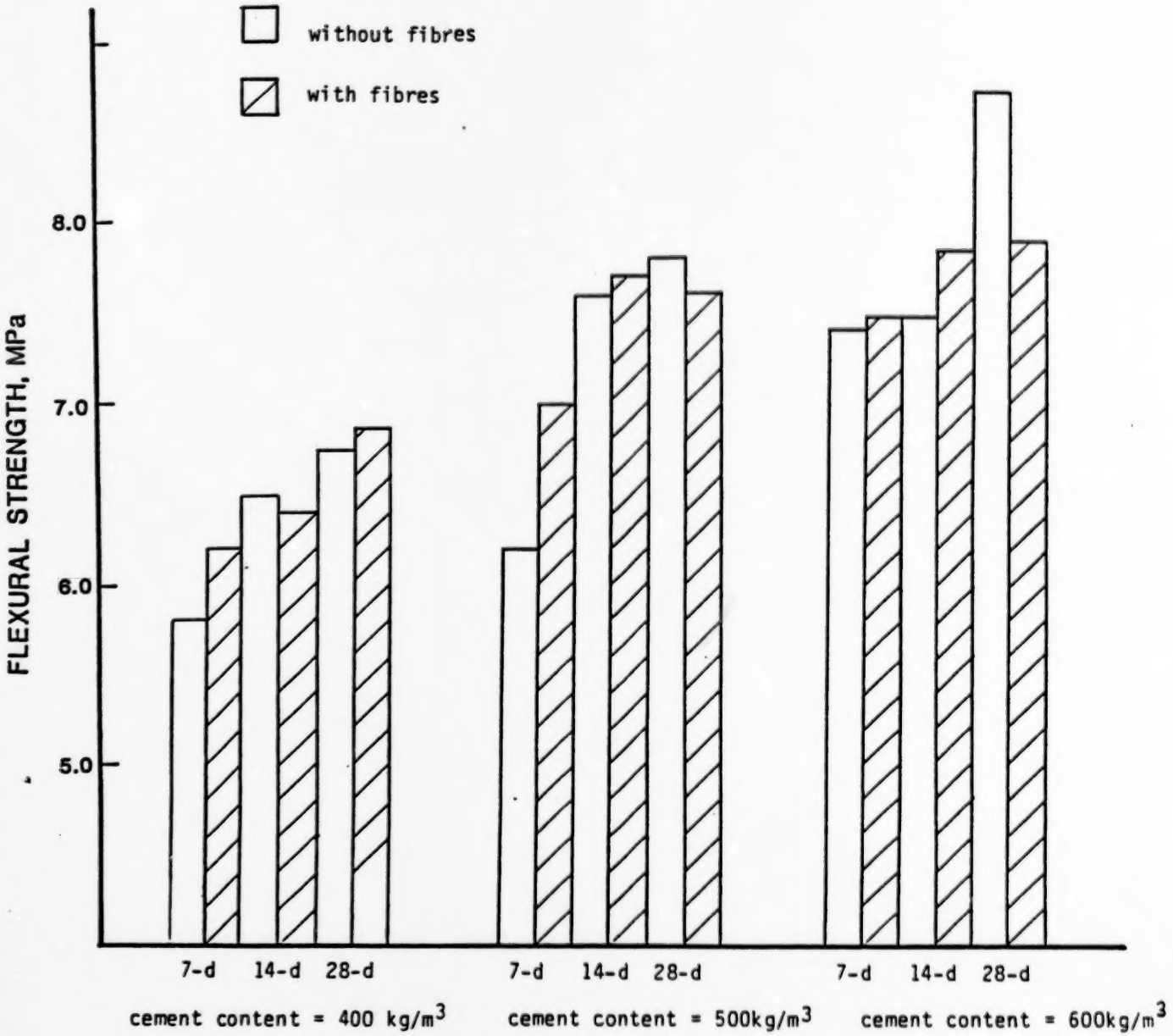


Fig. 5 Comparison of flexural strength for concrete with and without steel fibres

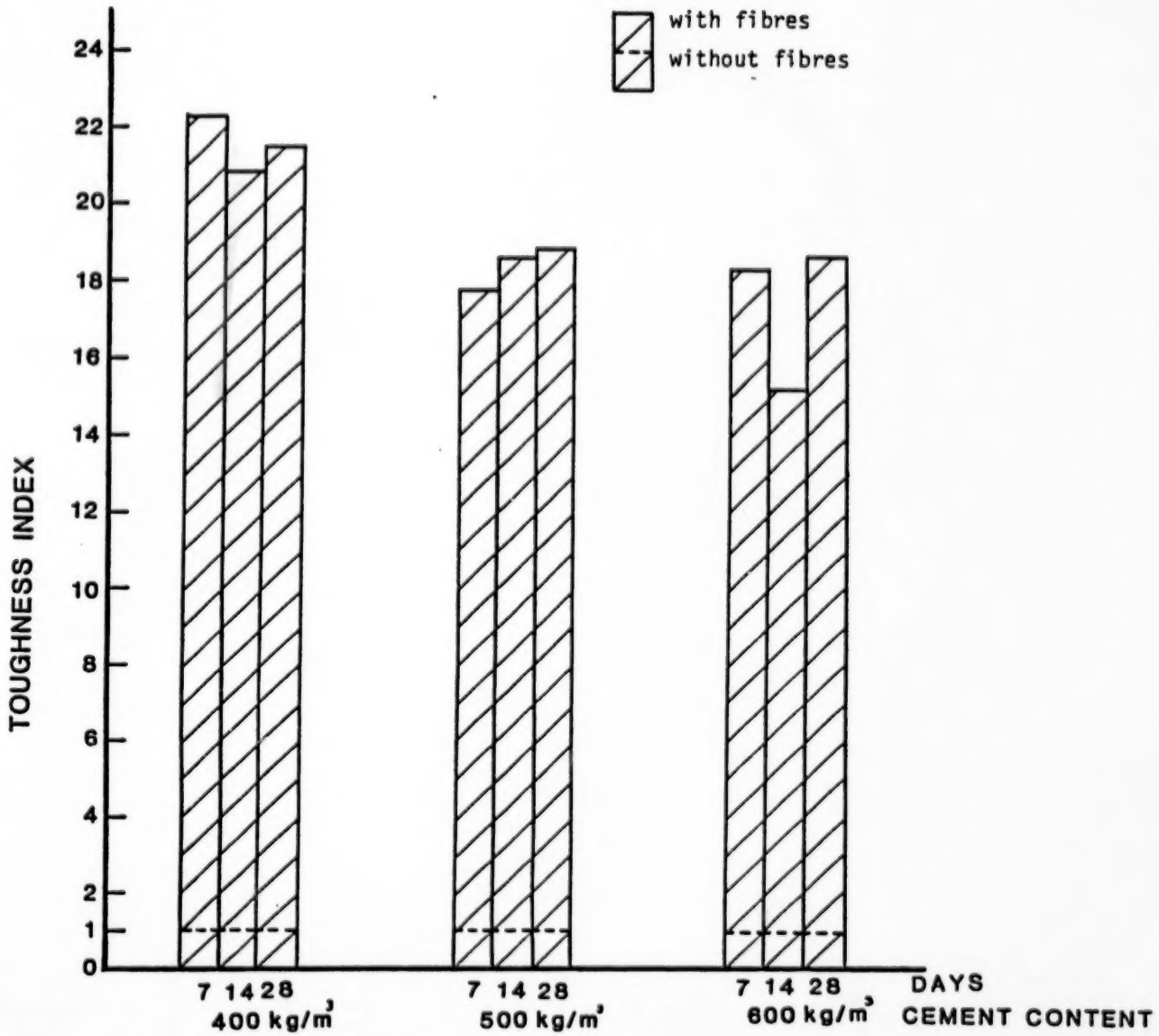


Fig. 6 Comparison of Toughness Index for concrete with and without fibres

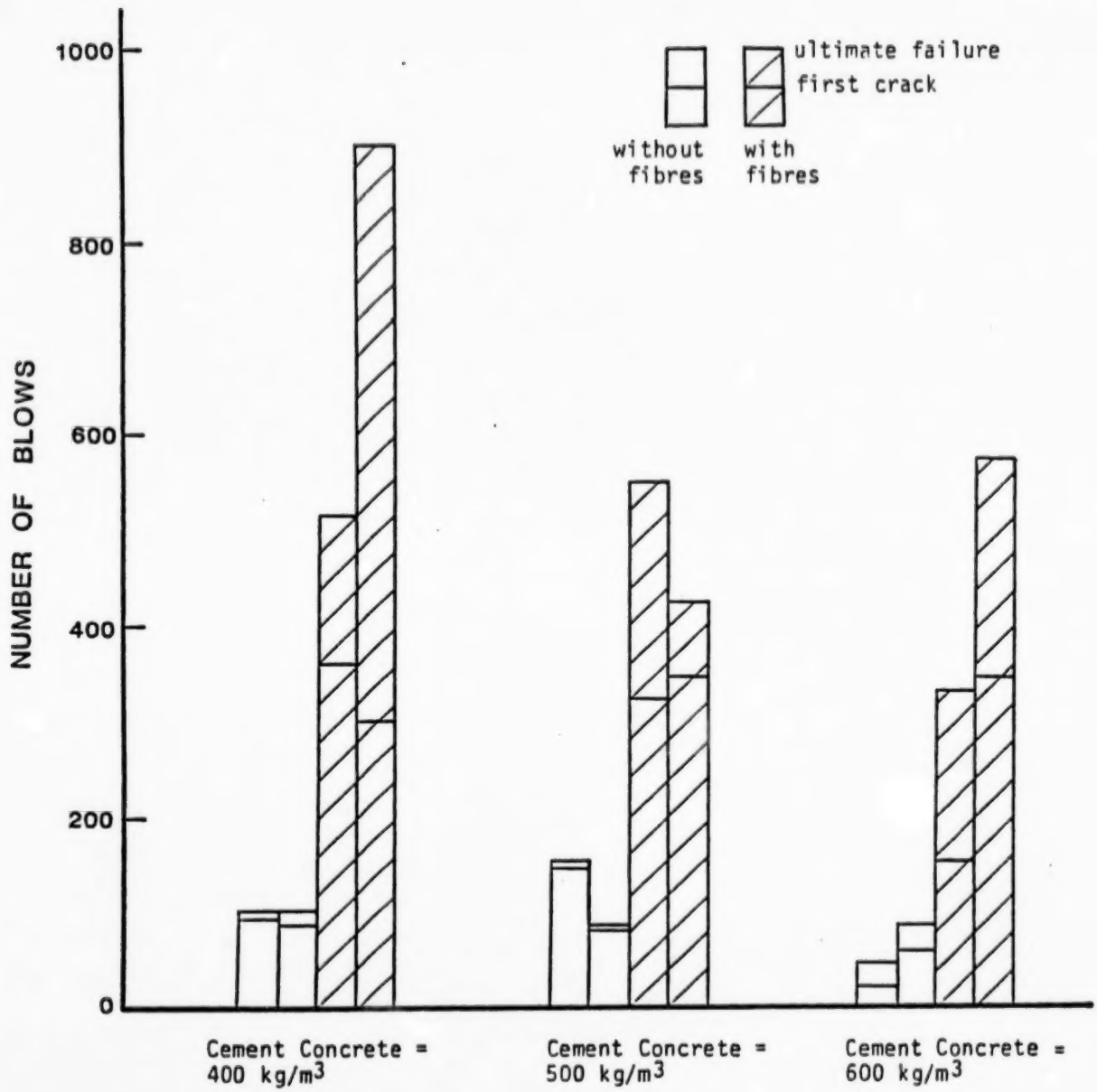


Fig. 7 Impact Resistance for sawn and cast specimens of concrete with and without steel fibres.

APPENDIX

Designation: C 995 – 83

Standard Test Method for TIME OF FLOW OF FIBER-REINFORCED CONCRETE THROUGH INVERTED SLUMP CONE[1]

This standard is issued under the fixed designation C 995; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the inverted slump-cone time of fiber-reinforced concrete, both in the laboratory and in the field.

1.2 This test method is considered applicable to freshly mixed concrete having coarse aggregate up to 1½ in. (38 mm) in size. It is not applicable to concrete that flows freely through the cone.

1.3 The values stated in inch-pound units are to be regarded as the standard. The metric equivalent of these units may be approximate.

2. Applicable Documents

2.1 *ASTM Standards:*

C 29 Test Method for Unit Weight and Voids in Aggregate[2]

C 31 Method of Making and Curing Concrete Test Specimens in the Field[2]

C 143 Test Method for Slump of Portland Cement Concrete[2]

C 172 Method of Sampling Freshly Mixed Concrete[2]

C 192 Method of Making and Curing Concrete Test Specimens in the Laboratory[2]

C 670 Practice for Preparing Precision Statements for Test Methods for Construction Materials[2]

3. Summary of Method

3.1 This test method determines the time required for fiber-reinforced concrete to flow through an inverted slump cone under internal vibration.

4. Significance and Use

4.1 This test method provides a measure of the workability of fiber-reinforced concrete.

4.2 The inverted slump-cone time is a better indicator than slump of the appropriate level of workability for fiber-reinforced concrete placed by vibration because such concrete can exhibit very low slump due to the presence of the fibers and still be easily consolidated.

4.3 The results may be used for mixture proportioning, quality control both in the laboratory and in the field, and in development and research.

4.4 The results obtained using this test method may be influenced by vibrator diameter, amplitude, and frequency.

5. Apparatus

5.1 *Cone*, shall be the mold specified in Test Method C 143.

5.2 *Bucket*—The container to receive the concrete shall be the 1-ft³ (30-L) capacity bucket specified in Test Method C 29.

5.3 *Positioning Device*—A device of the type shown in Fig. 1 shall be provided to center the cone in the bucket, prevent it from tilting, and maintain the small end of the cone 3 ±¼ in. (75 ±5 mm) from the bottom of the bucket.

5.4 *Vibrator*, shall be of the internal type specified in Methods C 31 or C 192, except that the vibrating element shall be 1 ± ⅛ in. (25 ± 3 mm) in diameter.

5.5 *Stopwatch*—One that measures elapsed

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[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.03.04 on Fiber-Reinforced Concrete.

Current edition approved Aug. 17, 1983. Published October 1983.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

time to the nearest second or less.

5.6 *Screeding Rod*—The rod used for screeding shall be the tamping rod specified in Test Method C 143.

6. Sampling

6.1 The sample of concrete for the test shall be representative of the entire batch. It shall be obtained in accordance with Method C 172, except that wet-sieving shall not be permitted.

7. Procedure

7.1 Center the positioning device on top of the bucket. Dampen the cone and place it in the positioning device. From the sample obtained in accordance with Section 6, fill the cone in three layers, each approximately one third of the volume of the cone. Avoid compacting the concrete, but lightly level each layer with a scoop or trowel to minimize the entrapment of large voids. Strike off the surface of the top layer by means of a screeding and rolling motion of the tamping rod. Protruding fibers which inhibit screeding may be removed by hand.

NOTE—A small amount of the sample may fall through the cone during the filling process. This effect is minimized by ensuring the volume of the first layer of concrete placed is large enough to bridge the opening in the cone.

7.2 Start the vibrator. Simultaneously start the stopwatch and insert the vibrating element centrally and vertically into the top of the sample in the cone. Let it descend at a rate such that it touches the bottom of the bucket in 3 ±1 s. Maintain the vibrating element approximately vertical and in contact with the bottom of the buacket. Avoid touching the cone with the vibrator. Stop the stopwatch when the cone becomes empty which occurs when an opening becomes visible at the bottom of the cone. Complete the portion of the test from the start of filling the cone through allowing the vibrating element to descend through the sample without interruption and within an elapsed time of 2 min. If the cone becomes plugged during the test, or fails to empty because of an excess of material that has fallen through during filling, disregard the result and make a new test on another portion of the sample.

7.3 Record the time in seconds.

8. Report

8.1 Report the time in seconds from initial immersion of the vibrating element to when the cone first becomes empty as the inverted slump-cone time.

8.2 Report the diameter, frequency, and amplitude of the vibrating element.

9. Precision and Accuracy

9.1 Based on limited data, the single-operator one-sigma limit has been found to be 1.0 s or less, and the between-operator one-sigma limit 1.5 s or less.[3]

9.2 A multilaboratory statement of precision is not appropriate for this test method.

[3] These are the 1S limits described in Practice C 670.

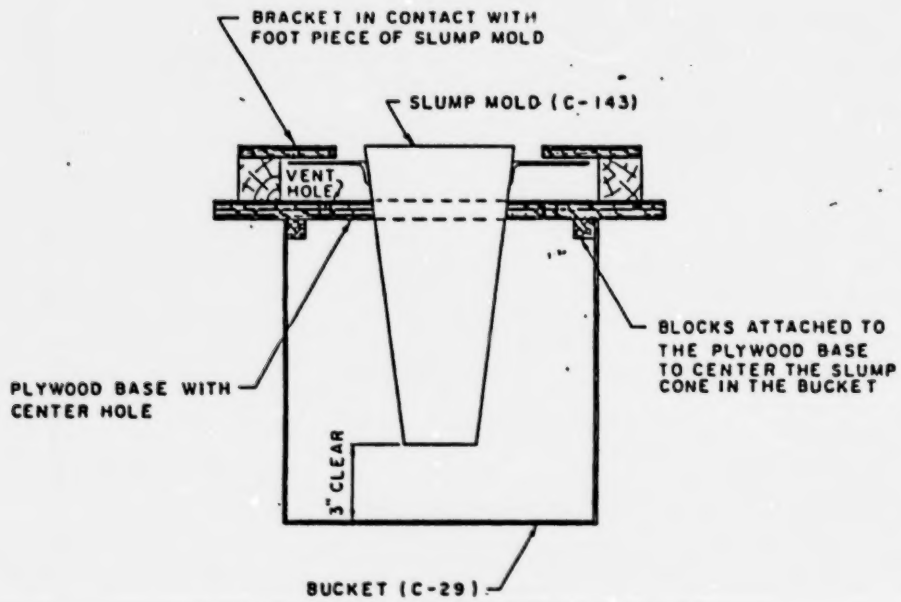
BRACKET IN CONTACT WITH FOOT PIECE OF SLUMP MOLD
SLUMP MOLD (C-143)
VENT HOLE
BLOCKS ATTACHED TO THE PLYWOOD BASE TO CENTER THE SLUMP CONE IN THE BUCKET
PLYWOOD BASE WITH CENTER HOLE
3" CLEAR
BUCKET (C-29)

FIG. 1 Method of Positioning the Inverted Slump Cone in the Bucket

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